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EVALUATION OF RUNOFF, EROSION, AND PHOSPHORUS MODELING SYSTEM - SIMPLE[1]

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ABSTRACT: The purpose of this study was to evaluate the performance of Spatially Integrated Models for Phosphorus Loading and Erosion (SIMPLE) in predicting runoff volume, sediment loss, and phosphorus loading from two watersheds. The modeling system was applied to the 334 ha QOD subwatershed, part of the Owl Run watershed, located in Fauquier County, Virginia, and to the 2240 ha watershed, Battle Branch, located in Delaware County, Oklahoma. Simulation runs were conducted at cell and field scales, and simulation results were compared with observed data. Runoff volume and dissolved phosphorus loading were measured at the Battle Branch watershed. Runoff volume, sediment yield, and total phosphorus loading were measured at the QOD site. SIMPLE tended to underestimate runoff volumes during the dormant period, from November to March. The comparison between observed and predicted dissolved phosphorus showed better correlation than for observed and predicted total phosphorus loading. Cell level simulations provided similar estimates of runoff volume and phosphorus loading when compared to field level simulations for both watersheds. However, observed sediment yields better compared with the values predicted from the cell level simulation when compared to field level simulation. Finally, results of model evaluation indicated that SIMPLE's predictive ability is acceptable for screening applications but not for site-specific quantitative predictions.
(KEY TERMS: erosion; modeling; phosphorus loss; runoff; watershed, GIS.)

INTRODUCTION

Phosphorus input to natural waters in the United States is of widespread concern. According to the United States Geological Survey watershed-based analysis, nonpoint sources were responsible for greater than 90% of the phosphorus in one-third of the studied rivers and streams (Newman, 1995). Nutrients, such as nitrogen and phosphorus, that originate from agricultural nonpoint sources have been identified as the main cause of cultural eutrophication in U.S. freshwater inland lakes and serve as an important source of nutrients to estuaries, affecting 57 percent of impaired lakes and 18 percent of estuaries (Daniel *et al.*, 1994). Eutrophication, the nutrient enrichment of natural waters, accelerates growth of algae or water plants. The decrease of dissolved oxygen associated with decay of these plants may cause suffocation of aquatic life. These negative effects associated with eutrophication of surface waters are important from both economic and environmental perspectives (Pierzynski *et al.*, 1994).

Commercial fertilizer and animal manure are the primary agricultural nonpoint sources of phosphorus. Between 1945 and 1993, the use of phosphorus fertilizers increased from 0.5 million to nearly 1.8 million metric tons per year. Farmers usually apply 24 percent to 38 percent more fertilizer than crops require because of uncertainties associated with weather and soil nutrient status (Puckett, 1995; Tsihrinzis *et al.*, 1996). During each year within the United States, the manure from 7.5 billion farm animals results in an additional estimated 1.8 million metric tons of phosphorus (Puckett, 1995), which must be managed properly to provide benefit as a fertilizer value and to minimize potential adverse environmental impact. Constituents of surface-applied manure can be lost in runoff from intense storms that occur shortly after application (Edwards *et al.*, 1996). Because of environmental concerns and the widespread problem of phosphorus loss, a need exists for an assessment tool for the modeling of animal waste and P fertilizer

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levels, from application to final amounts of bioavailable forms, in order to successfully modify management practices.

There are currently a variety of distributed parameter watershed and basin scale models available to predict sediment and phosphorus loading to surface water. Examples of these models include AGNPS (Young *et al.*, 1989), ANSWERS (Storm *et al.*, 1988), SQWRRB-WQ (Arnold *et al.*, 1990), SWAT (Arnold *et al.*, 1993), and others. These models require a significant number of input parameters, and data to accurately estimate these parameters are often not available. When detailed data are available, these more sophisticated models may provide more accurate results. However, the uncertainty in model predictions due to parameter uncertainty may out weigh the use of simpler methods of estimating sediment and phosphorus loading (Heatwole and Shanholtz, 1991; Shanholtz *et al.*, 1990; Hession and Shanhotz, 1988).

SIMPLE (Spatially Integrated Models for Phosphorus Loading and Erosion) is a compromise between current complex distributed parameter watershed models and less sophisticated methods (Sabbagh *et al.*, 1995). Although SIMPLE has several significant simplifications over more complex models; it requires significantly fewer parameters, thereby potentially reducing the uncertainty in model predictions.

The overall goal of this study was to test SIMPLE's predictive ability. The specific objectives were to evaluate SIMPLE on its hydrologic components (runoff and erosion) and nutrient predictive methods, to evaluate SIMPLE as a screening tool, and to compare differences in using field and cell scale predictions.

SIMPLE was developed and is being maintained by the Biosystems Engineering Department, Oklahoma State University, Stillwater, Oklahoma. Components of the model are briefly described below. A detailed description of the modeling system and its components is presented by Sabbagh *et al.* (1995). Also, the various functions of the modeling system and description of the input/output parameters are provided in Smith (1996).

MODEL DESCRIPTION

SIMPLE consists of a Phosphorus Transport Model (PTM), a Digital Terrain Model (DTM), and a Database Manager (DM). The system components communicate with one another via interface software, which was specifically developed as a SUN workstation X-view Windows application. The modeling system can be used in conjunction with the Geographic Information System (GIS), Geographic Resource Analysis Support System (GRASS) (CERL, 1988). The format of the spatial data required by the system is the same as the format of ASCII files generated from GRASS raster data. However, SIMPLE does not require GRASS to run and can be used independently.

SIMPLE provides two scales to simulate sediment and phosphorus loading, cell scale and field scale (Figure 1). A cell is the smallest element of a map in which data is stored. A field is a group of adjacent cells with homogeneous land use and management practice characteristics. The field-based option requires less simulation time because there are fewer fields than cells. However, considerable error may be produced if there is significant variation in soil and topographic properties within a field.

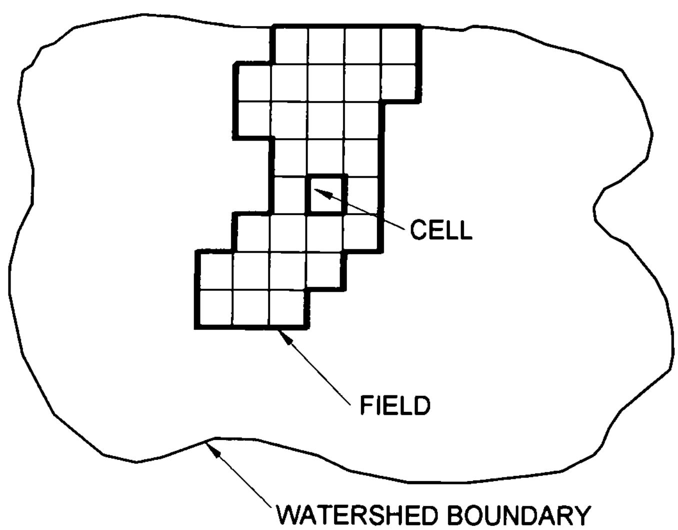

Figure 1. Cell and Field Concept Within a Watershed.

The Phosphorus Transport Model:

The Phosphorous Transport Model (PTM) is divided into four modules: runoff, soil erosion, phosphorus, and delivery ratio. A detailed description of the PTM model components and performance is presented in Sabbagh *et al.* (1995).

Runoff volume is estimated by the Soil Conservation Service (SCS) curve number method (U.S. Soil Conservation Service, 1985). To estimate the daily curve number we use a weighed curve number, CN, estimated by:

$$CN = W_1\, CN_1 + W_2\, CN_2 + W_3\, CN_3 \qquad (1)$$

where W_1, W_2, and W_3 are weighing factors, and CN_1, CN_2, and CN_3 are curve numbers for antecedent soil moisture conditions 1, 2 and 3, respectively. The weighing factors are estimated using:

$$W_1 = 1 \quad \text{if } V_p \le f_1; \quad W_1 = \frac{f_1}{V_p} \quad \text{if } V_p > f_1 \qquad (2)$$

$$W_2 = 0 \quad \text{if } V_p \le f_1; \quad W_2 = \frac{V_p - f_1}{V_p} \quad \text{if } f_1 < Vp \le f_2;$$

$$W_2 = \frac{f_2 - f_1}{V_p} \quad \text{if } V_p > f_2 \qquad (3)$$

$$W_3 = 0 \quad \text{if } V_p \le f_2; \quad W_3 = \frac{V_p - f_2}{V_p} \quad \text{if } Vp > f_2 \qquad (4)$$

where V_p is rainfall volume (cm), f_1 and f_2 are 1.25 cm and 2.75 cm during the dormant season, and 3.5 cm and 5.25 cm during the growing season, respectively (Smedema and Rycroft, 1983).

The Universal Soil Loss Equation (USLE) is used to estimate soil erosion (U.S. Soil Conservation Service, 1978):

$$A_e = 2.24 \text{ R K L S C P} \qquad (5)$$

where A_e is gross annual soil loss, R is a rainfall factor, K is a soil erosivity factor, LS is the length and slope factor, C is a cover factor, and P is a practice factor. The amount of sediment reaching the stream (A_s) is estimated by:

$$A_s = A_e \times DR \qquad (6)$$

where DR is the delivery ratio. The phosphorus module estimates the daily phosphorus status associated with the application of commercial fertilizer and animal manure. The total phosphorus loading is determined as the sum of dissolved phosphorus in runoff and sediment bound phosphorus. The dissolved phosphorus in runoff and sediment bound phosphorus are calculated as follows:

$$P_{qc} = \frac{1}{K} * P_{soil} \qquad (7)$$

$$P_q = P_{qc} * q \qquad (8)$$

$$P_{seed} = P_{soil} * A_s * PER \qquad (9)$$

where P_{qc} is a concentration of dissolved phosphorus in runoff water (mg/l), P_q is the amount of dissolved phosphorus (kg/ha) (P_{soil} is the phosphorus concentration in the soil layer mg/kg of soil), q is the runoff volume (cm), Kd the distribution coefficient (cm^3/g), and PER is the phosphorus enrichment ratio. Kd is a constant taken as 175 cm^3/g (Williams *et al.*, 1984)

The relationship developed by Heatwole and Shanholtz (1991) is used to calculate the delivery ratio, which accounts for the trapping of sediment and sediment-bound phosphorus along with deposition of these materials to the stream. The delivery ratio is determined by:

$$DR = \exp(-k_f D_s S_f) \qquad (10)$$

$$S_f = S_{fmin} + \exp[-k_2(S_2 + S_0)] \qquad (11)$$

where DR is a delivery ratio; D_s is distance to the stream; S is slope; and k_1, k_2, S_0, and S_{fmin} are constants with values of 0.0161, 16.1, 0.057, and 0.6, respectively (Heatwole and Shanholtz, 1991). It is important to mention that the delivery ratio does not account for deposition in streams (i.e., the amounts of sediment and phosphorus reaching the stream are considered to be the amount reaching the watershed outlet).

The Digital Terrain Model

The Digital Terrain Model (DTM) provides estimates of the topographic parameters required for running the PTM. The DTM uses digital elevation model data (DEM) to estimate the land slope of the cell, distance to stream, and the slope along that distance. It includes procedures to detect and fill depressions, define flow direction, calculate flow accumulation values, delineate channel networks, define drainage boundaries, and extract cell and drainage characteristics such as slope (θ), path length (L), and the product of path and slope (Lθ). A detailed description of the DTM is provided by Sabbagh *et al.* (1994). The database manager (DM) is a tool for developing the soil and land use parameters. It can be used to generate the data layers that contain, for each cell, information on soil characteristics, such as the percent clay, (%CL), percent organic carbon (%C), curve number (CN), soil erodibility factor (K), slope length (λ), soil available phosphorus content (Pi), and soil pH.

Model Input Parameters

There are four input data sets required for running the model: soil, topography, vegetation cover, and management practice. The soil data set includes percent clay content, percent organic carbon, the curve number, the soil erodibility factor, and the soil available phosphorus content. The topography data set describes the slope, the path length, and the path slope. The other two data sets define the changes in the crop cover factor with time, the growing season, and the Phosphorus application rates, type and dates. The Curve number and soil available phosphorus content are the most important parameters for predicting runoff volume and phosphorus loading.

PROCEDURES

The modeling system was applied to two sites having different topography, geology, soil, land use, and climatic conditions: Battle Branch in Oklahoma and QOD in Virginia. Simulation runs were conducted at cell and field scales. For each site, digital maps describing the spatial distribution of soils, land use, topography, and field boundaries were obtained, and the soil and management practices databases were developed. Each watershed was divided into 30m x 30m cells. SIMPLE DTM and DM modules were used to calculate, at the cell level, soil and topographic related parameters (CN, %CL, %C, pH, K, λ, Pi, θ, L, and Lθ), and to generate the required input data layers. The cell by cell simulations were based on the data generated by the DTM and the DM. To conduct the simulation runs at field scale, soil and topographic related parameters were calculated for each field. Parameters for each field were assumed to be the area weighted mean of the cells that located within the boundaries of that field.

Two methods were used to test the model's predictive ability: (1) linear regression, and (2) acceptance criteria. The linear regression method defines the closeness of fit, and provides an understanding of the correlation between observed and predicted values. The closer the slope of the regression line is to unity and its intercept is to zero, the better the model predicts the observed data. The coefficient of determination, r^2, represents the level at which the variation in the dependent variable is explained by the regression line (Haan, 1991). An r^2 value of 1.0 indicates that all the data points are represented by the regression line.

The acceptance criteria for the model was based upon recommended statistical analysis of residual errors, such as Mean Square Error (MSE) and root mean square error called also the normalized objective function (NOF) (Pennell *et al.,* 1990; Loague and Green, 1991). The normalized objective function (NOF) is the ratio of the MSE to the overall mean of the observed parameter. MSE and NOF are calculated by:

$$\mathrm{MSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \tag{12}$$

$$\mathrm{NOF} = \frac{\mathrm{MSE}}{X_a} \tag{13}$$

where x_i and y_i are the i^{th} observed and predicted values, respectively; and X_a is the mean of the observed values. STDD is a measure of the dispersion of the simulated data from the observed data, which represents the average error between observed and predicted results. NOF is a dimensionless measure of observed and predicted value differences and can therefore be used to rank the effectiveness of SIMPLE on different watersheds.

Hedden (1986) suggested that NOF can be used to evaluate the overall model performance based on the acceptance criteria. He stated that for "screening" applications where parameters are not calibrated for the site, the model results should be within an order of magnitude of the observed values, which corresponds with a NOF value of 9.0. According to Hedden (1986), for "site-specific" applications where data are measured on-site, the model should be able to match field observations within a factor of 2.0, and NOF value of 1.0. Ideally the minimum values of these parameters should be 0.0 (Loague and Green, 1991). Hession *et al.* (1994) suggested however that an NOF value of more than 1.0 satisfies the "screening" criteria, and an NOF value of less than 1.0 satisfies the "site-specific" criteria. These criteria were also used in this evaluation.

Meeting the site-specific criteria reveals that the model can be used for estimating and determining the results associated with a particular management practice, i.e., a particular input data set. Meeting the screening criteria, on the other hand, implies that the model is suitable only for comparing results generated from different management practices.

SITE AND DATA DESCRIPTION

Battle Branch Watershed

The Battle Branch watershed is located in southern Delaware County in northeast Oklahoma (Figure 2). This hydrologic unit, which possesses an area of about 2240 ha, is located in the Ozark Highland Land Resource Area. The topography is primarily rough steep hills with blackjack-postoak tree cover. Battle

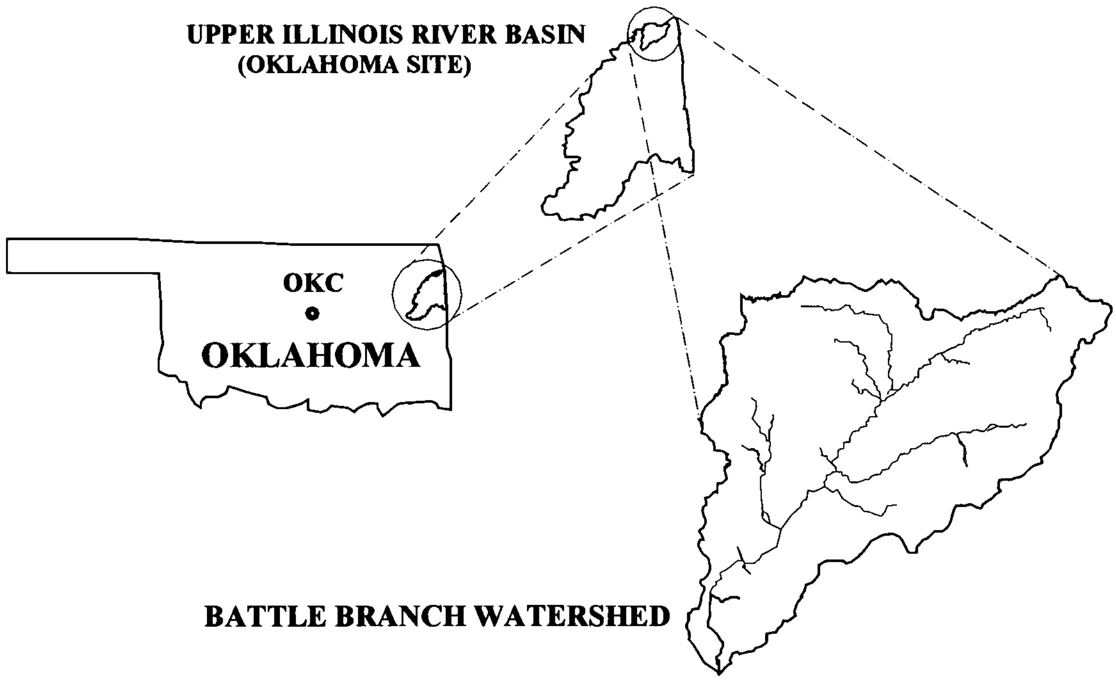

Figure 2. Location of the Battle Branch Watershed in Oklahoma.

Branch is a tributary of the Illinois River in Oklahoma, and the primary contributor stream for Lake Tenkiller. The watershed is in one of the nation's leading poultry producing areas, containing 31 chicken houses within the unit. In addition to intensive poultry production, there are nine dairies with 550 dairy animals and about 1000 unconfined beef cattle within the watershed area. The major land use within the watershed is agriculture.

The Battle Branch watershed area includes 19 different soil types (Table 1). The four predominant soil types are associated with the Clarksville-Baxter-Locust type. The Clarksville Stony silt loam has the highest runoff potential with area of 342 ha and 20 percent to 50 percent slopes. The other three soil types consist of the Baxter Locust complex, with an area of 286 ha and slopes from 3 percent to 5 percent; the Baxter Cherty silt loam, with an area of 274 ha and 1 percent to 3 percent slopes; and the Clarksville Stony silt loam, with an area of 275 ha and slopes from 5 percent to 20 percent. There are 178 different fields in the study area, which are grouped into six land use types: pasture (58 percent); woods (33 percent); Meadow-hay (6 percent); and cropped land, urban, and homesteads (3 percent). Soil samples were collected from each field and tested for plant available phosphorus content. The curve numbers were obtained based on the land use cover and the hydrologic soil group as described in U.S. Soil Conservation Service (1972). The phosphorus levels range between 10 ppm on forested land to 1200 ppm on pasture. The average plant available phosphorus in pasture areas is 130 ppm.

Daily precipitation values were obtained from the National Climatic Data Center for Oklahoma. Flow and water quality data for the period extending from August 1986 to November 1987 were provided by the Oklahoma Conservation Commission, the agency that was overseeing the monitoring program in the watershed. A flow stage meter located at the outlet of the Battle Branch creek was used to measure the water level in the stream. For each storm event, water samples were collected and analyzed in a laboratory for total phosphorus content using a spectrophotometer. Flow measurements at three different stages were obtained and plotted to develop a rating table. The stage charts and rating curves were digitized, and total flow, interval flow, and total phosphorus loading from rising, falling, and baseline flow were calculated. The water samples were not tested for total suspended solids or sediment bond phosphorus. Thus these data sets were not available.

QOD Subwatershed

The 334 ha QOD subwatershed is a part of the 1153 ha Owl Run watershed, located in Fauquier County, Virginia, about 165 km southwest from Washington D.C. (Figure 3). More than 70 percent of the area is used for agriculture. The narrow, rolling to

TABLE 1. Soil Characteristics Within the Battle Branch Watershed.

Soil Type	Percent Slope	K	HGRP	L	BD	%CL	%OC
Baxter SiL	1-3	0.33	B	152	1.37	19	1.76
Baxter Cherty SiL	1-3	0.33	B	152	1.37	19	1.76
Baxter SiL	3-5	0.33	B	121	1.37	19	1.76
Captina SiL	1-3	0.36	B	152	1.43	12	1.18
Clarksville very Cherty SiL	1-8	0.39	B	15	1.46	12	0.74
Clarksville Stony SiL	5-20	0.43	B	60	1.43	25	0.74
Clarksville Stony SiL	20-50	0.43	B	30	1.43	25	0.74
Jay SiL	0-2	0.37	C	167	1.51	18	1.18
Locust Cherty SiL	1-3	0.40	B	152	1.48	12	0.59
Newtonia SiL	0-1	0.37	B	182	1.41	18	1.18
Newtonia SiL	1-3	0.37	B	152	1.41	18	1.18
Sallisaw SiL	0-1	0.41	B	15	1.46	33	0.74
Sallisaw SiL	1-3	0.41	B	15	1.46	33	0.74
Sallisaw Gravelly SiL	1-3	0.39	B	15	1.46	12	0.74
Sallisaw Gravelly SiL	3-8	0.39	B	15	1.46	12	0.74
Stasser SiL	0	0.34	B	15	1.35	25	1.76
Stasser Gravelly L	0	0.34	B	15	1.35	25	1.76
Stigler SiL	0-1	0.36	D	182	1.43	12	1.18
Taloka SiL	0-1	0.44	D	182	1.45	25	0.44

Note: K = Erodibility factor.
HGRP = Hydrologic soil group.
L = Slope length (m).
BD = Bulk density (g/cm^3).
%CL = Percent clay content.
%OC = Percent organic carbon content.

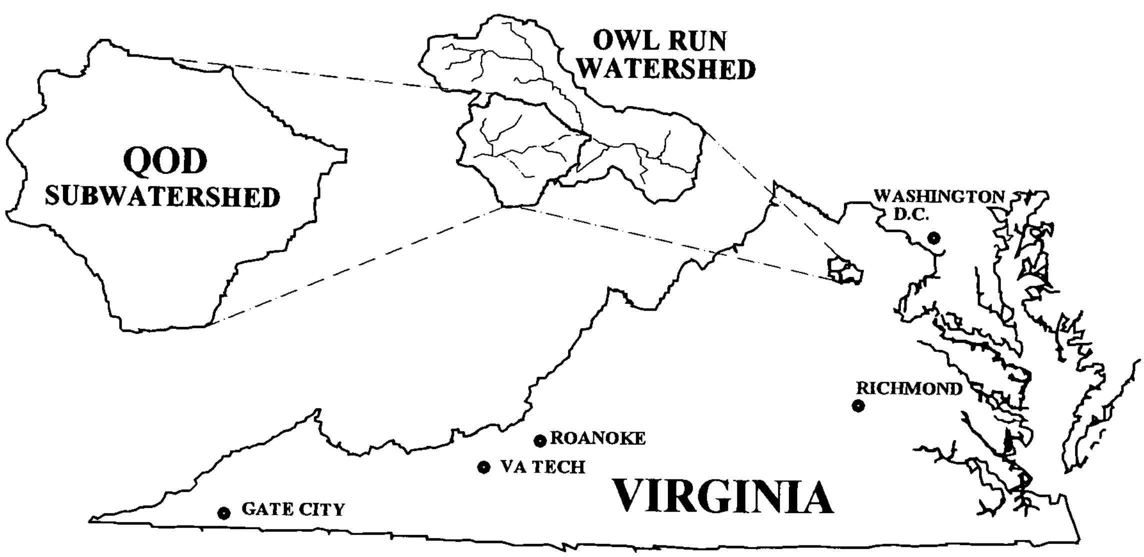

Figure 3. Location of the OWL RUN Watershed with the QOD Subwatershed in Northern Virginia.

hilly uplands, underlaid chiefly by granitic rocks, is located between the foothills. The climate of Fauquier County is the humid continental type with an average annual rainfall of about 104 cm, fairly well distributed throughout the year, although the greatest amount occurs during spring and summer seasons.

The soils in the watershed are generally shallow (0.3 to 0.6 meters deep) silt loam overlying Triassic shale. The shale layer is exposed in some areas, and the more intensely used fields are thought to be eroding at high rates. The major soil series underlying the watershed are Penn, Bucks and Montalto associations, which cover more than 72 percent of the watershed area. The Penn soils are derived from Triassic red shale and sandstone, the silt loam from the shale and the loam from the sandstone. The soil surface is reddish-brown to dark reddish-brown. Plant available phosphorus concentrations in the surface soil layer range between 10 ppm to 50 ppm, with an average concentration value of 30 ppm. Slopes range from 2 percent to 7 percent for undulating topography and 7 percent to 14 percent for rolling hills. Runoff is medium, and internal drainage is medium to rapid.

There are 22 fields in this study area, which are grouped into six land use types: pasture (19 percent); woods (25 percent); Hay (13 percent); cropped land (32 percent); Homestead (10 percent); and pond (1 percent). Two major dairy operations are located in the watershed; the waste management of these operations impacts the quality of the watershed runoff water.

Precipitation, runoff, sediment and phosphorus loading from the QOD watershed were monitored beginning in 1986. Data describing soil characteristics (Table 2) and crop cover factors were obtained from the Fauquier County Soil Survey and from the Soil Conservation Service Agricultural Handbook 537 (U.S. Soil Conservation Service, 1978). A detailed description of the monitoring program conducted on this site, as well as information describing crop production practice and fertilizer application is provided in Mostaghimi *et al.* (1989).

RESULTS AND DISCUSSION

SIMPLE's simulations at cell and field levels were conducted for a 16-month period (August 1986 to November 1987) on the Battle Branch watershed and a 20-month period (January 1987 to June 1988) on the QOD subwatershed. Model results obtained from each site were analyzed independently. For the Battle Branch watershed, the runoff volume and dissolved

TABLE 2. Soil Characteristics Within the QOD Subwatershed.

Soil Type	Percent Slope	K	HGRP	L	BD	%CL	%OC
Bowmansville SiL	0-2	0.32	C	84	1.50	12	0.88
Buck SiL	2-7	0.37	B	69	1.46	18	1.03
Calverton SiL	2-7	0.43	C	69	1.48	18	0.74
Croton SiL	0-5	0.37	D	69	1.41	25	1.18
Elbert SiL	0-2	0.43	D	84	1.35	25	1.18
Goldvein Gritty Gravelly SiL	7-14	0.28	C	61	1.48	18	0.74
Irredell SiL	2-7	0.32	D	69	1.48	16	0.74
Kelly SiL	0-7	0.37	D	69	1.49	18	0.74
Montalto SiL	2-7	0.32	C	69	1.41	25	1.18
Montalto SiL	7-14	0.32	C	61	1.41	25	1.18
Montalto Stony SiL	7-14	0.24	C	61	1.49	25	1.18
Penn SiL	2-7	0.28	C	69	1.48	12	1.18
Penn SiL	7-14	0.28	C	61	1.48	12	1.18
Penn SiL	7-14	0.28	C	61	1.48	12	1.18
Penn SiL	14-25	0.17	C	46	1.48	12	1.18
Rowland SiL	0-2	0.43	C	69	1.43	12	1.76
Stone Rolling and Hilly Land	7-25	0.32	C	46	1.48	12	1.18
Wadesboro Fine SL	2-7	0.37	B	69	1.46	18	1.03
Wadesboro SiL	7-14	0.37	B	61	1.46	18	1.03
Wehadkee SiL	0-2	0.49	D	84	1.38	17	2.06

Note: K = Erodibility factor.
HGRP = Hydrologic soil group.
L = Slope length (m).
BD = Bulk density (g/cm^3).
%CL = Percent clay content.
%OC = Percent organic carbon content.

phosphorus loading were the only parameters analyzed, since sediment and total phosphorus loading data were not available. For the QOD site, the model ability to predict runoff volume, sediment loss and total phosphorus loading was evaluated.

Monthly observed and predicted values for the considered watersheds in the analysis were compiled. The monthly observed and predicted data for each parameter were fitted to linear regression models, with the observed as independent and predicted as dependent variable. The significance of regression line slopes and intercepts were tested, and the correlation coefficient was determined for each regression line. The MSE and NOF values were also calculated for all parameters. The MSE and NOF values were determined based on the monthly observed and predicted values.

Runoff Volume

For Battle Branch, the monthly runoff volumes are presented in Figure 4. The average monthly volumes from cell and field simulations were 31 percent and 32 percent smaller than the total observed runoff volumes (Table 3). The slope and intercept of the regression line associated with both cell and field level simulated monthly runoff volumes were 1.03 and -1.29, respectively, with an r^2 value of 0.89 (Table 4). The r^2 values indicate that the relationships between

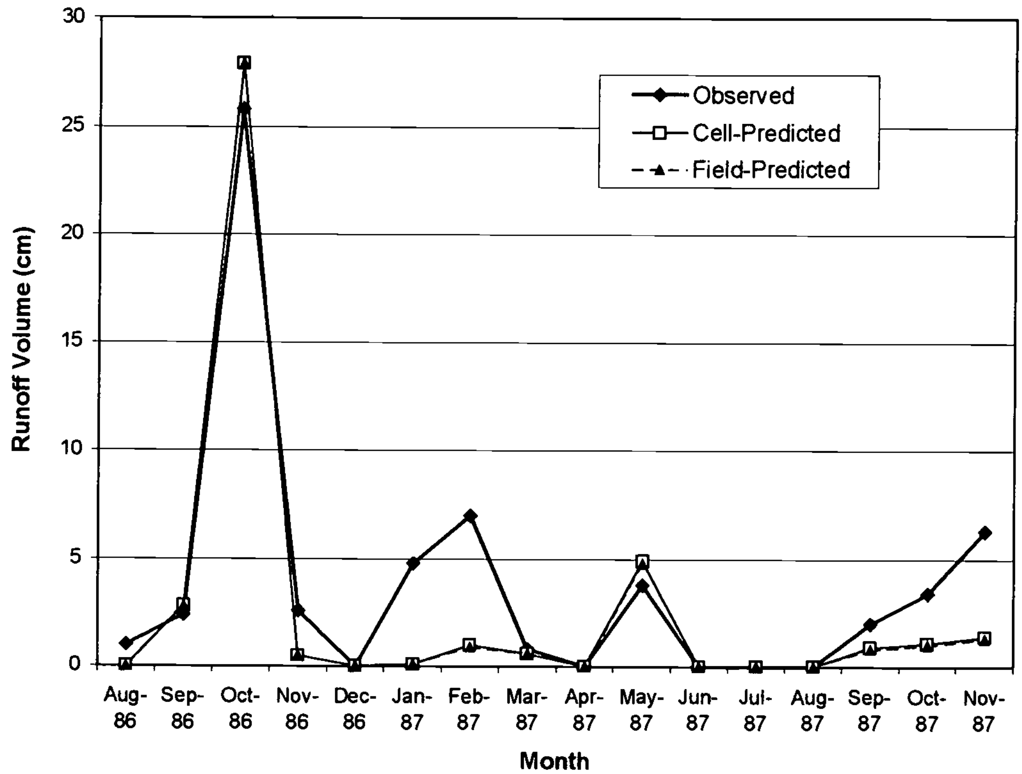

Figure 4. Comparison Between Observed and Predicted Monthly Runoff Volumes (cm) for the Battle Branch Watershed.

TABLE 3. Monthly Predicted Mean Runoff Volumes and Phosphorus Loading, STDD and NOF Values for Battle Branch Watershed.

Parameter		Observed Mean	Mean	Predicted STDD	NOF
Runoff volume (cm/month)	Cell	3.74	2.57	2.50	0.67
	Field	3.74	2.55	2.52	0.67
Phosphorus Loading (kg/ha/month)	Cell	0.05	0.09	0.11	2.41
	Field	0.05	0.08	0.10	2.23

TABLE 4. Testing the Slope and Intercept of the Runoff Volume and Phosphorus Loading Regression Lines for Battle Branch Watershed.

		r^2	Parameter	Parameter Estimate	T for H_0* Parameter	Prob > |T|**
Runoff Volume	Cell	0.89	Intercept	-1.29	-1.86	0.09
			Slope	1.03	0.31	> 0.50
	Field	0.89	Intercept	-1.29	-1.87	0.09
			Slope	1.03	0.30	> 0.50
Phosphorus Loading	Cell	0.66	Intercept	0.00	0.11	> 0.50
			Slope	1.88	2.44	0.03
	Field	0.63	Intercept	0.00	0.11	> 0.50
			Slope	1.73	2.06	0.06

*Parameter = 0, for intercept.
Parameter = 1, for slope.
**Conclusion: If prob |T| > 0.05, conclude H_0.

observed and predicted values are well represented by the regression line. The NOF values were 0.67 (Table 3), revealing that the model satisfied the "site-specific" criteria.

In the QOD subwatershed, the monthly runoff volumes are presented in Figure 5. The runoff volumes from cell and field simulations were within 2 percent of the observed volume (Table 5). The slope and intercept of the regression lines were 0.84 and 0.28, respectively, for the cell level simulation, and 0.26 and 0.83 for field level simulation (Table 6). The cell and field r^2 values of the regression lines were 0.38 (Table 6), which means that only 38 percent of the variability in the data can be described by these lines. The NOF values were 1.22 and 1.21 for cell and field, respectively (Table 5), indicating that the model met the "screening" criteria for predicting runoff volume, but not the "site-specific" criteria.

The results show that SIMPLE tended to underestimate runoff volumes during the dormant period, from November to March, particularly for the Battle Branch site, where the average observed monthly volume for that period was about six times the corresponding predicted value. This can be attributed to the fact that the model does not take in consideration lateral subsurface flow of the water, i.e the possibility of water to resurface in lower areas of the field. Such assumption is reasonable during the growing season, where significant portion of the water in the soil profile is lost through evapotranspiration (ET), thus keeping the soil profile in relatively dry condition. During the dormant season however, ET is relatively small, and the moisture content in the soil profile is high, thus increasing the possibility for lateral subsurface flow.

The results also indicate no significant differences in the runoff volumes generated from cell and field level simulations. Such observation is expected when the runoff volume is a function of the curve number. The curve number value is directly correlated with the land use type and the soil hydrologic group. In most cases, a field includes one dominant soil type and has one landuse; thus, the average CN value, which is used to represent the field, is similar to the CN values of the individual cells that make up that field.

Sediment Loss

For QOD, the monthly sediment loss amounts are presented in Figure 6. The average monthly sediment yields predicted from cell and field simulations for QOD were about twice the total observed soil loss (Table 5). The slope and intercept of the regression line associated with cell level values were 1.47 and 29.5, respectively, with an r^2 value of 0.83 (Table 6). The slope and intercept of the field level sediment yield regression line were 0.99 and 47.8, with an r^2 of 0.50. T-tests showed that the slopes and intercepts of the sediment yield regression lines were not significantly different than 1 and 0 (α = 0.05), respectively. The NOF values were 2.1 for cell simulations and 2.4 for field simulations (Table 5).

Results show that although the model overestimated the monthly sediment loss, the trends in the predicted values were similar to the trend in the observed values (Figure 6). The cause of the discrepancy between the model results and the observed data is not clear. One could speculate that values of the

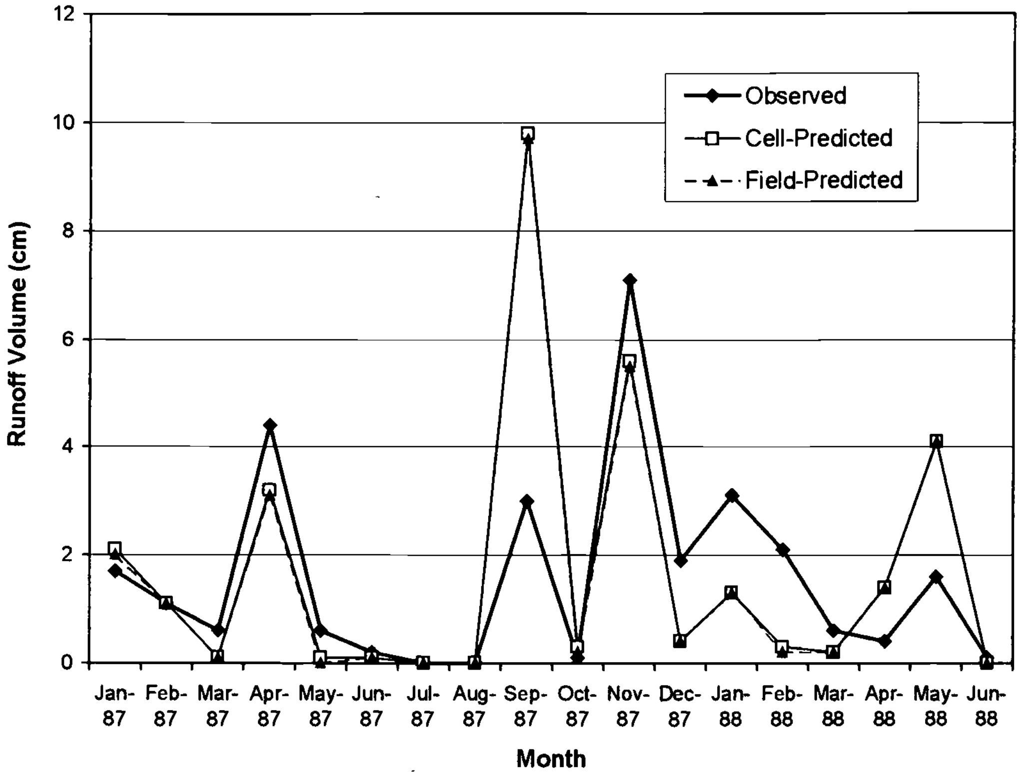

Figure 5. Comparison Between Observed and Predicted Monthly Runoff Volumes for the QOD Subwatershed.

TABLE 5. Monthly Predicted Mean Runoff Volumes and Phosphorus Loading, STDD and NOF Values for QOD Subwatershed.

Parameter		Observed Mean	Mean	Predicted STDD	NOF
Runoff volume (cm/month)	Cell	1.65	1.67	2.00	1.22
	Field	1.65	1.63	2.00	1.21
Sediment Loss (kg/ha/month)	Cell	47.3	98.9	97.7	2.10
	Field	47.3	94.6	111.9	2.40
Phosphorus Loading (kg/ha/month)	Cell	0.15	0.09	0.33	2.25
	Field	0.15	0.09	0.34	2.36

constants in the equations used to calculate the delivery ratio (Equations 10 and 11) need to be adjusted for the watershed. Also, better estimates of the crop cover factors in Equation (5) may be needed.

Phosphorus Loading

For Battle Branch, the monthly dissolved phosphorus loading values are presented in Figure 7. In Battle Branch, the monthly dissolved phosphorus values from cell and field simulations were 95 percent and 80 percent, respectively, greater than the corresponding observed value (Table 3). The slope and intercept of the regression line associated with cell level simulated P loading were 1.88 and 0.0, respectively, with r^2 value of 0.66 (Table 4). Values of the slope, intercept, and r^2 for the field level phosphorus loading regression line were 1.73, 0.0, and 0.63, respectively (Table 4). T-tests showed that the slope and the intercept of the regression lines were not significantly different than 1 and 0 ($\alpha = 0.05$), which suggests a good correlation between the monthly observed and predicted values. The NOF values for cell and field were 2.41 and 2.23, respectively (Table 3).

TABLE 6. Testing the Slope and Intercept of the Runoff Volume, Sediment Loss, and Phosphorus Loading Regression Lines for QOD Subwatershed.

		r^2	Parameter	Parameter Estimate	T for H_0* Parameter	Prob > |T|**
Runoff Volume	Cell	0.38	Intercept	0.28	0.42	> 0.50
			Slope	0.84	-0.58	> 0.50
	Field	0.38	Intercept	0.26	0.40	> 0.50
			Slope	0.83	-0.62	> 0.50
Sediment Loss	Cell	0.83	Intercept	29.5	1.57	0.15
			Slope	1.47	2.79	0.02
	Field	0.50	Intercept	47.8	1.71	0.1
			Slope	0.99	-0.04	> 0.50
Phosphorus Loading	Cell	0.34	Intercept	0.06	2.03	0.06
			Slope	0.21	-11.5	< 0.01
	Field	0.24	Intercept	0.06	2.10	0.05
			Slope	0.17	-10.9	< 0.01

*Parameter = 0, for intercept.
Parameter = 1, for slope.
**Conclusion: If prob |T| > 0.05, conclude H_0.

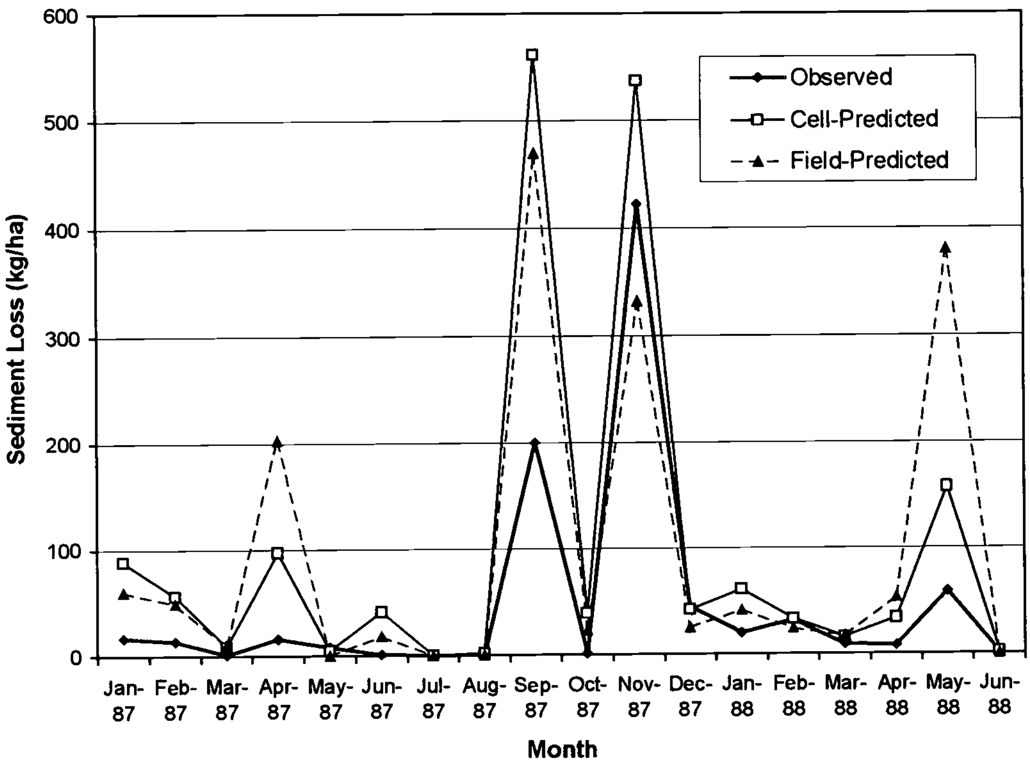

Figure 6. Comparison Between Observed and Predicted Monthly Sediment Loss for the QOD Subwatershed.

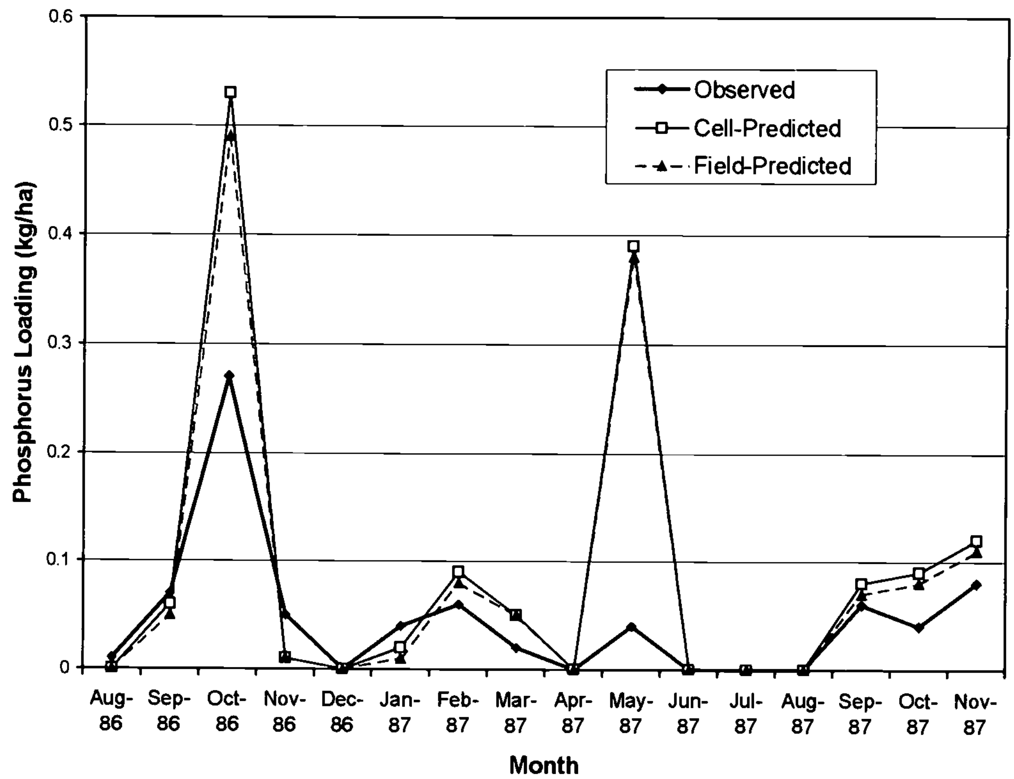

Figure 7. Comparison Between Observed and Predicted Monthly Dissolved Phosphorus Loading for the Battle Branch Watershed.

In the QOD subwatershed, the total phosphorus loading from cell and field simulations were about 62 percent the corresponding observed values (Table 5). The monthly values are shown in Figure 8. The slope and intercept of the regression line associated with cell level simulated total phosphorus loading were 0.21 and 0.06, respectively, with r^2 value of 0.34 (Table 6). Values of the slope, intercept, and r2 for the field level total phosphorus loading regression line were 0.17, 0.06, and 0.24, respectively (Table 6). T-tests showed that, for both regression lines, the slopes are significantly different than 1, but the intercepts are not significantly different than 0 (α = 0.05). The cell and field NOF values were 2.25 and 2.36, respectively (Table 5).

Results of the analysis show that, SIMPLE overestimated monthly phosphorus loss on both watersheds, except for the month of November 1987, where the observed value for QOD was about four times larger than the corresponding predicted values. The model tendency to overestimate phosphorus loss can be attributed to the method used to determine the concentration of dissolved phosphorus (P_{qc}) in runoff volume. Equation (7) shows that P_{qc} increases linearly with the increase of phosphorus concentration in the soil (P_{soil}). However, other studies (Sharpley and Smith, 1989; *Storm et al.,* 1988) show that the rate of increase of P_{qc} with the increase of Psoil is not constant, and that this rate tends to decrease with increase of P_{soil}. These studies suggest that using a linear equation may lead to overestimation of P_{qc} for soils with high Psoil values.

Results also indicate no significant differences in the dissolved (Battle Branch) and total phosphorus (QOD) generated from cell and field level simulations, and the model is more suitable for screening applications than for site specific applications.

SUMMARY AND CONCLUSION

The overall objective was to evaluate the predictive ability of SIMPLE at a watershed scale. SIMPLE is a watershed scale hydrology and phosphorus transport model developed as a tool for assessing the impacts of agricultural management practices on sediment and phosphorus loading. The model simulates runoff volume, sediment yield, and phosphorus loading at cell and field scales, with a cell being the smallest management unit in which data are stored, and field being a group of contiguous cells with homogeneous land use and management practices.

Data from two sites, Battle Branch in Oklahoma and QOD in Virginia, were used to evaluate SIMPLE's performance in predicting runoff, sediment

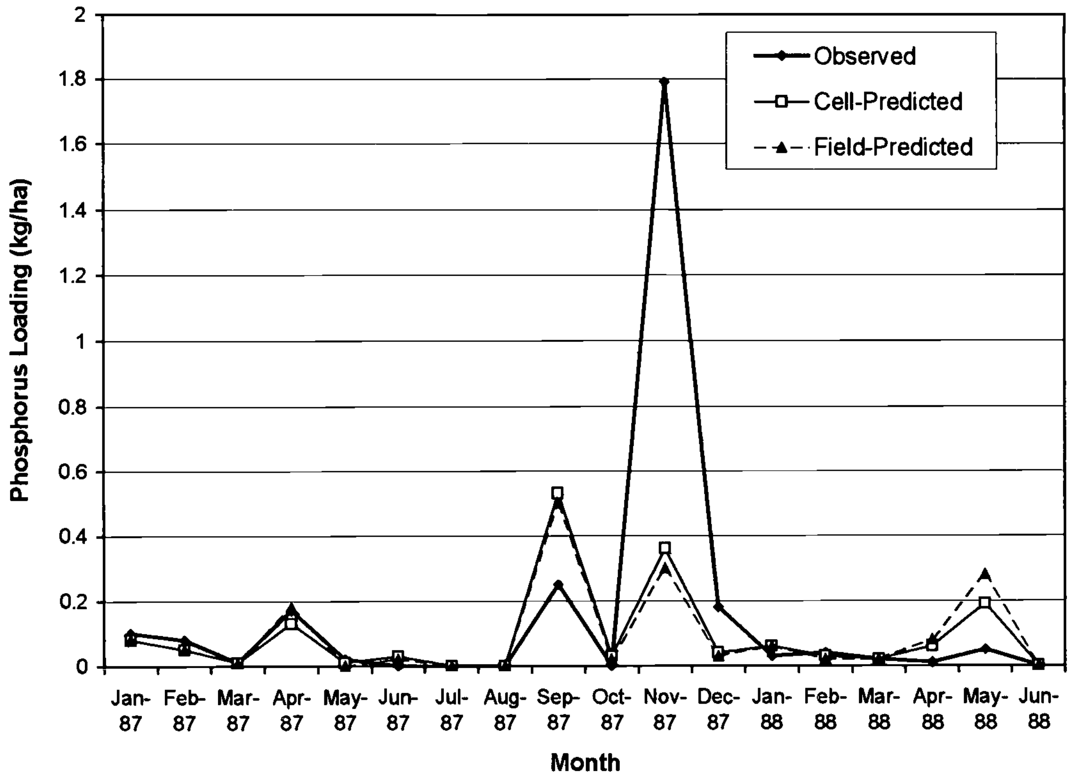

Figure 8. Comparison Between Observed and Predicted Monthly Total Phosphorus Loading for the QOD Subwatershed.

yield, and phosphorus loading. Digital maps describing the spatial distribution of soils, land use, topography, and field boundaries were obtained for each site and the soil and management practices databases were developed. Each site was divided into 30m x 30m cells, and data sets describing the soil and topographic parameters were developed at the cell level and used to calculate the field level data sets.

Testing SIMPLE's predictive ability included evaluating SIMPLE for its hydrologic components (runoff and sediment) and nutrient predictive methods, evaluating SIMPLE as a screening tool, and comparing differences in using field and cell scale predictions. Several conclusions were drawn from this study:

1. SIMPLE tended to underestimate runoff volumes during the dormant period (from November to March).

2. The correlation between observed and predicted dissolved phosphorus was significantly higher (Battle Branch) than the correlation between observed and predicted total phosphorus loss (QOD).

3. Cell level simulations provided similar estimates of runoff volume and phosphorus loading when compared to field level simulations. However, observed sediment yields were better correlated with the values predicted from the cell level than field level simulation.

4. The model met the screening criteria but not the site-specific criteria, implying that the model is suitable only for comparing results generated from different management practices.

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